Northeast Coastal and Barrier Network
Protocol Development Summary
(Sept. 2005)

Protocol: Estuarine Eutrophication

Parks Where Protocol will be Implemented: CACO, GATE, FIIS, SAHI, ASIS, GEWA, COLO

Justification/Issues being addressed:
Approximately one quarter of the NPS land area within the Coastal and Barrier Network is submerged. These estuaries, bays, and lagoons serve as islands of relatively pristine aquatic habitat within the Northeastern urban corridor. The North Atlantic coastal parks are dependent on high-quality aquatic resources to sustain the complex estuarine and nearshore ecosystems they represent. Diverse threats to NPS estuaries exist, including natural disturbances (e.g. storms, sea-level rise), direct impacts of human activities (e.g. fishing, boating, dock construction), indirect effects of watershed development, and disasters. Of these, park managers throughout the network have repeatedly identified threats to coastal water quality as one of their highest priority management issues. Much of the watershed area of NPS coastal ecosystems lies outside protective park boundaries and is subject to intense developmental pressures. Therefore, there is great potential for human disturbances to coastal watersheds to result in increased nutrient loading to park estuaries. Estuaries can generally assimilate some degree of enrichment without major ecological ramifications, but excessive nutrient inputs typically lead to dense blooms of phytoplankton and fast-growing macroalgae, loss of seagrasses, and decreased oxygen availability in sediments and bottom waters. Ultimately, cascading effects include changes in the species composition and abundance of invertebrates, decline in fish and wildlife habitat value, and the collapse of fin- and shellfish stocks. Protecting the ecological integrity of park estuaries depends on implementing a scientifically-based monitoring program that is capable of diagnosing local causes of nutrient enrichment, detecting changes in nutrient loads, and determining if nutrient inputs are near to exceeding thresholds that would result in shifts in ecosystem structure and function.

Monitoring Goals, Questions and Objectives to be addressed by the Protocol:
NCBN Goal:
Provide information to NCBN park mangers on the status and trends of park estuarine water quality for use in management decisions and contribute to understanding and describing the condition of marine and coastal areas.

Monitoring Questions:
Are nutrient loads to park estuaries increasing?
Are estuarine resources changing in response to nutrient inputs?
What are the sources of nutrient enrichment?

Monitoring Objective 1:
Determine long-term trends in summertime levels of dissolved oxygen concentration, turbidity, attenuation of photosynthetically active radiation, temperature, salinity and suspended chlorophyll concentrations in estuarine waters and organic carbon in estuarine sediment in selected NCBN park sites.

Monitoring Objective 2:
Determine the distribution and abundance of submerged aquatic vegetation beds in selected areas in NCBN parks.

Monitoring Objective 3:
Determine long-term, inter-annual trends in seagrass condition (shoot density percent cover and biomass) in selected estuarine areas of NCBN parks.

Vital Signs:
Estuarine water chemistry, estuarine water quality, estuarine water clarity, estuarine sediment chemistry, seagrass distribution, seagrass condition

Measures:
Dissolved oxygen, temperature, salinity, chlorophyll a, photosynthetically active radiation (par), turbidity, % organic carbon of surficial sediments, sav bed size, structure and location, sav within bed: percent cover, shoot density, biomass,

Justification of Each Vital Sign:

Vital Sign: Estuarine water chemistry

Measurements: dissolved oxygen, temperature, and salinity

Organic matter on the estuarine sediment surface and within the sediments is mineralized by microbial decomposers, a process which consumes oxygen. Consequently, as the pool of sedimentary organic matter increases in response to nutrient enrichment, intense benthic microbial metabolism can result in reduced concentrations of dissolved oxygen in bottom waters and a decrease in the depth of the oxic-anoxic interface within the sediments (Day et al. 1989, Cloern 2001). Ultimately, the shift to anaerobic benthic metabolism will stimulate sulfate reduction and cause an accumulation of hydrogen sulfide in pore waters (Herbert 1999, Cloern 2001). The increases in extent and duration of bottom water anoxia and concentration of toxic sulfide compounds with nutrient enrichment have obvious negative implications for benthic fauna. Dissolved oxygen concentrations below 2.0-5.0 mg/l cause declines in the diversity and abundance of estuarine fauna (NRC 2000). Therefore, use of dissolved oxygen as a monitoring variable provides indirect information on nutrient loads and direct information on threats to estuarine consumers.

Two of the most important physical characteristics of seawater are temperature and salinity. Although temperature and salinity data are not directly applicable to questions regarding estuarine nutrient enrichment, these variables are critical to interpreting the responses of other parameters.

Vital Sign: Estuarine water clarity

Measurements: Photosynthetically active radiation light attenuation (par) and turbidity

The principal environmental control on Submerged Aquatic Vegetation (SAV) productivity and distribution is light availability (e.g. Dennison and Alberte 1982, 1985; Dennison 1987, Duarte

1991), specifically the amount of photosynthetically available radiation (PAR, light between 400-700 nm) transmitted to plant leaves. A primary factor contributing to the attenuation of PAR through the water column is phytoplankton concentration (Dennison et al. 1993, Gallegos 1994, Krause-Jensen and Sand-Jensen 1998). Therefore, in systems showing increases in phytoplankton biomass with nutrient load, PAR attenuation is correlated with nutrient enrichment (Borum 1996).

<u>Vital Sign:</u> Estuarine water quality

<u>Measurements:</u> Chlorophyll a

Nutrient enrichment of coastal waters frequently stimulates phytoplankton production and results in increased phytoplankton biomass (Sand-Jensen and Borum 1991, Duarte 1995, Borum 1996). A strong linear relationship exists between input of dissolved inorganic nitrogen and phytoplankton production (when both are log transformed) in deep, phytoplankton-based marine systems (Nixon et al. 1996). Chlorophyll a, an indicator of phytoplankton biomass, shows a similar relationship in deep-water systems (Nixon 1992). Because of this, many national, regional, state, and local estuarine monitoring and assessment programs include measures of chlorophyll a concentration as an indicator of nutrient loading (e.g. Bricker 1999, Gibson et al. 2000, USEPA 2001b).

<u>Vital Sign:</u> Seagrass Distribution

<u>Measurements:</u> submerged aquatic vegetation (sav) bed size, structure and location. within sav-bed, percent cover, shoot density and biomass

The correlation between increased nutrient loading and declines in SAV distribution has been documented for estuaries worldwide (reviewed by Sand-Jensen and Borum 1991, Duarte 1995, Harlin 1995). Experimental studies have confirmed the causal relationships linking nutrient input, increased algal production, and decreased macrophyte growth and survival (Neckles et al. 1993, Short et al. 1995, Taylor et al. 1995, Sturgis and Murray 1997). The primary mechanism for loss of SAV in response to increased nutrient load is attenuation of light by fast-growing phytoplankton, epiphytic microalgae, and free-floating macroalgae, resulting in reduced availability of light at macrophyte leaf surfaces (Sand-Jensen 1977, Bulthuis and Woelkerling 1983, Twilley et al. 1985, Sand-Jensen and Borum 1991). Changes in seagrass distribution gives information on the long-term effects of estuarine eutrophication.

<u>Vital Sign:</u> Seagrass Condition

<u>Measurements:</u> within sav-bed, percent cover, shoot density and biomass

The correlation between increased nutrient loading and declines in SAV distribution has been documented for estuaries worldwide (reviewed by Sand-Jensen and Borum 1991, Duarte 1995, Harlin 1995). Experimental studies have confirmed the causal relationships linking nutrient input, increased algal production, and decreased macrophyte growth and survival (Neckles et al. 1993, Short et al. 1995, Taylor et al. 1995, Sturgis and Murray 1997). The primary mechanism for loss of SAV in response to increased nutrient load is attenuation of light by fast-growing phytoplankton, epiphytic microalgae, and free-floating macroalgae, resulting in reduced availability of light at macrophyte leaf surfaces (Sand-Jensen 1977, Bulthuis and Woelkerling 1983, Twilley et al. 1985, Sand-Jensen and Borum 1991). Although changes in seagrass distribution track long-term changes, short-term changes in condition will precede loss and therefore should be monitored in order to provide early warning capabilities.

Vital Sign: Estuarine sediment organic carbon

Measurements: Percent organic carbon of surficial sediments

Water column and benthic processes are closely coupled in shallow coastal systems, so responses to nutrient enrichment may be observed in the sedimentary environment (Herbert 1999, Cloern 2001). Some of the organic production stimulated by nutrient inputs may be exported to nearshore waters, but this is generally a small fraction of the total primary production. For example, 10-15% of the primary production in Narragansett Bay is exported from the system (Nixon et al. 1995), and some systems with high rates of primary production export less organic matter than they produce (Smith and Hollibaugh 1993). Thus the majority of increased production that is stimulated through nutrient enrichment is metabolized or stored within the system. Much of this authochthonous organic matter sinks to the benthos and contributes to the pool of sediment organic material. Thus, organic carbon in the sediments may increase with nutrient load. Striking evidence is found in sediment cores from Chesapeake Bay, where a doubling of organic carbon content over the past 80 years corresponds to a period of dramatic increases in nutrient load (Cornwell et al. 1996).

Basic Approach for all Vital Signs:
Estuarine nutrient monitoring variables have been limited to those that are well justified scientifically and deemed feasible from both practical and economic perspectives. Two of these variables are sampled on infrequent time scales. These are sediment organic carbon content and benthic faunal species composition. Methods for these variables are well established (US EPA 2001) so feasibility testing will not be conducted. This EPA guidance will be translated into a network-specific protocol that includes sampling stations, sampling frequency, identification of contract laboratories and cost sourcing, and references to standard procedures. Similarly, data on submerged aquatic vegetation will be available for some of the parks to acquire from outside sources. Where it is not available, methodological protocols will be provided so that parks (or the network) can build in-house capability or obtain contract service for the data.

Other variables that will be included in the NCBN estuarine nutrient monitoring protocol are chlorophyll a, dissolved oxygen concentration, attenuation of photosynthetically active radiation, and the required ancillary data of temperature and salinity. Field-based feasibility testing has been conducted at COLO, GATE and FIIS, to work out spatial and temporal sampling requirements and to assess logistical constraints. Among these, there are functional equivalents for large coastal lagoon systems, tidal creek dominated systems, and systems, and coastal embayment. EPA National Coastal Assessment staff have assisted in developing a spatial sampling scheme.

A fully documented protocol has been developed for all of the variables. This protocol includes strategies for continuous and discrete sampling approaches, probability-based spatial sampling strategies, methods for incorporating non-Park Service data, and instruction on reporting and interpreting results. This protocol is compatible with the NPS National Marine Water Quality Monitoring Effort (led by Dr. Charles Roman from the NCBN Technical Steering Committee; project PI Hillary Neckles is also on the advisory committee), and with the EPA National Coastal Assessment (already committed to assisting us w/ probability-based sampling design).

Principal Investigators and NPS Lead:

Protocol development will be completed through cooperative agreement with the USGS Patuxent Wildlife Research Center, 26 Ganneston Drive. Augusta, ME 04330.
Principal Investigators: Hilary A. Neckles and Blaine S. Kopp
NPS Leads: Bryan Milstead and Sara Stevens

Development Schedule, Budget, and Expected Interim Products:

Regional- and national-level protocols already existed for many of the vital sign measurements identified for inclusion in the NCBN estuarine nutrients monitoring protocol. Therefore, existing measurement protocols have been converted to meet NPS standards (Oakley et al. 2003) and a draft full monitoring protocol is included with the NCBN Phase III Report on December 15, 2004. After peer review, revision and approval, the implementation of the protocol will take place in 2006. $128,000 was budgeted in FY 2004 for protocol development. An additional $78,200 was added to the existing agreement in FY 2005.

Literature Cited

Bulthuis, D. A. and W. J. Woelkerling. 1983. Biomass accumulation and shading effects of epiphytes on leaves of the seagrass, Heterozostera tasmanica, in Victoria, Australia. Aquatic Botany 16:137-148.

Borum, J. 1996. Shallow waters and land/sea boundaries. pp. 179-203 in B. B. Jrrgensen and K. Richardson (eds), Eutrophication in coastal marine ecosystems. American Geophysical Union, Washington, DC.

Bricker, S. B., C. G. Clement, D. E. Pirhalla, S. P. Orlando, and D. R. G. Farrow. 1999. National estuarine eutrophication assessment: effects of nutrient enrichment in the nation’s estuaries. NOAA, National Ocean Service, Special projects Office and the National Centers for Coastal Ocean Science, Silver Spring, MD. 71pp.

Cloern, J. E. 2001. Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210:223-253.

Cornwell, J. C., D. J. Conley, M. Owens, and J. C. Stevenson. 1996. A sediment chronology of the eutrophication of Chesapeake Bay. Estuaries 19:488-499.

Day, J. W., Jr., C. A. S. Hall, W. M. Kemp, and A. Yáñez-Arancibia. 1989. Estuarine ecology. John Wiley & Sons, Inc. 558 pp.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom, and R. A. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. Bioscience 43:86-94.

Dennison, W. C. 1987. Effects of light on seagrass photosynthesis, growth and depth distribution. Aquatic Botany 27:15-26.

Dennison, W. C. and R. S. Alberte. 1982. Photosynthetic responses of Zostera marina L. (eelgrass) to in situ manipulations of light intensity. Oecologia 55:137-144.

Dennison, W. C. and R. S. Alberte. 1985. Role of daily light period in the depth distribution of Zostera marina (eelgrass). Marine Ecology Progress Series 25:51-61.

Duarte, C. M. 1991. Seagrass depth limits. Aquatic Botany 40:363-377.

Duarte, C. M. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. Ophelia 41:87-112.

Gallegos, C. L. 1994. Refining habitat requirements of submersed aquatic vegetation: role of optical models. Estuaries 17:187-199.

Gibson, G. R., M. L. Bowman, J. Gerritsen, and B. D. Snyder. 2000. Estuarine and coastal marine waters: bioassessment and biocriteria technical guidance. EPA 822-B-00-024. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Harlin, M. M. 1995. Changes in major plant groups following nutrient enrichment. pp. 173-187 in A. J. McComb (ed.), Eutrophic shallow estuaries and lagoons. CRC Press, Inc., Boca Raton, FL.

Hemminga, M.A., and C.M. Duarte. 2000. Seagrass Ecology. Cambridge University Press, Cambridge, United Kingdom.

Herbert, R. A. 1999. Nitrogen cycling in coastal marine ecosystems. FEMS Microbiology Reviews 23:563-590.

Krause-Jensen, D. and K. Sand-Jensen. 1998. Light attenuation and photosynthesis of aquatic plant communities. Limnology and Oceanography 43:396-407.

Neckles, H. A., R. L. Wetzel, and R. J. Orth. 1993. Relative effects of nutrient enrichment and grazing on epiphyte-macrophyte (Zostera marina L.) dynamics. Oecologia 93:285-295.

Nixon, S.W. 1992. Quantifying the relationship between nitrogen input and the productivity of marine ecosystems. Proceedings of the International Symposium for Ecology, Technical Conference 5. Shimane, Japan. 1990. p 57-83.

Nixon, S.W., J.W. Ammerman, L.P. Atkinson, V.M. Berounsky, G. Billen, W.C. Boicourt, W.R. Boynton, T.M. Church. D.M. Ditoro, R. Elmgren, J.H. Garber, A.E. Giblin, R.A. Hahnke, N.J.P. Owens, M.E.Q. Pilson, and S.P. Seitzinger. 1996. The fate of nitrogen and phosphorus at the land-sea margin of the North Atlantic Ocean. Biogenchemistry 35:131-180.

Oakley, K. L., L.P. Thomas, and S. G. Fancy. 2003. Guidelines for Long-term monitoring protocols. Wildlife Society Bulletin 31 (4): xx-xx.

Sand-Jensen, K. and J. Borum. 1991. Interactions among phytoplankton, periphyton, and macrophytes in temperate freshwaters and estuaries. Aquatic Botany 41:137-175.

Short, F.T., and R.G. Coles (eds.). 2001. Global Seagrass Research Methods. Elsevier Science B.B., Amsterdam. 473p.

Smith, S. V. and J. T. Hollibaugh. 1993. Coastal metabolism and the oceanic organic carbon balance. Review in Geophysics 31:75-89.

Sturgis, R. B. and L. Murray. 1997. Scaling of nutrient inputs to submersed plant communities: temporal and spatial variations. Marine Ecology Progress Series 152:89-102.

Taylor, D. I., S. W. Nixon, S. L. Granger, B. A. Buckley, J. P. McMahon, and H. –J. Lin. 1995. Responses of coastal lagoon plant communities to different forms of nutrient enrichment. Aquatic Botany 52:19-34.

Twilley, R. R., W. M. Kemp, K. W. Staver, J. C. Stevenson, and W. R. Boynton. 1985. Nutrient enrichment of estuarine submersed vascular plant communities. 1. Algal growth and effects on production of plants and associated communities. Marine Ecology Progress Series 23:179-191.

U.S. EPA. 2001b. National coastal assessment: field operations manual. U.S. Environmental Protection Agency, Office of Research and Development, National Health and

Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. EPA 620/R-01/003.